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BIOFILTRATION SWALE PERFORMANCE, RECOMMENDATIONS, AND DESIGN CONSIDERATIONS

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CONTENTS

CONTENTS (continued)

CONTENTS (continued)

TABLES

ILLUSTRATIONS

SECTION 1
REPORT HIGHLIGHTS

Recently, biofiltration swales have been increasingly used to manage the quality of stormwater runoff from roads and other impervious surfaces associated with urban development. This study was conducted to determine the pollutant removal effectiveness of a grassy swale designed specifically for its water treatment benefits. In addition, the study sought to measure effectiveness of two swale configurations differing in length and water residence time. The two configurations are referred to as the 200-foot and 100-foot configurations. The 200-foot configuration was found to have a hydraulic residence time of approximately 9 minutes; the 100-foot configuration, 4.6 minutes. In addition, the Manning's roughness coefficient, referred to as Manning's n, was also measured in the 200-foot configuration.

RESULTS

Major findings of the study are summarized below.

Pollutant Removal Performance

The biofiltration swale studied (which was designed according to criteria given in Horner, 1988) was seen to consistently remove particulate pollutants such as total suspended solids (83 percent removal), turbidity (65 percent) and metals of largely particulate character, such as lead, zinc, iron and aluminum (63 percent to 72 percent). Materials which adhere to the grass surfaces, such as oil and grease and total petroleum hydrocarbons (TPH) are also effectively removed (about 74 percent).

Metals of less particulate character, such as copper; and dissolved metals were generally less consistently removed. Dissolved zinc removal averaged 30 percent for the 200-foot configuration. Dissolved copper, iron, and aluminum removals were negative on average, although for some events positive removals were seen. Dissolved lead was always below the detection level, so conclusions about removal could only be inferred from the behavior of other similar metals.

Nutrients were removed to varying degrees, with best removals seen for bio-available phosphorus (40 percent), followed by total phosphorus (29 percent). Poor or negative removals were seen, on average, for dissolved nutrients, such as ortho phosphorus (ortho-P) and nitrate+nitrite-nitrogen (nitrate+nitrite-N).

The removal of fecal coliform bacteria was highly variable. Some of the data showed good removals, while other data showed elevated concentrations in the outflow. These increased loadings were probably caused by external sources (such as pet wastes) and bacterial multiplication on the swale bottom and on the wooden flume bottom. Figure 1-1 summarizes the pollutant removals associated with the 200-foot swale configuration ranked in order of treatment effectiveness. The figure represents the average of removals seen for each event.

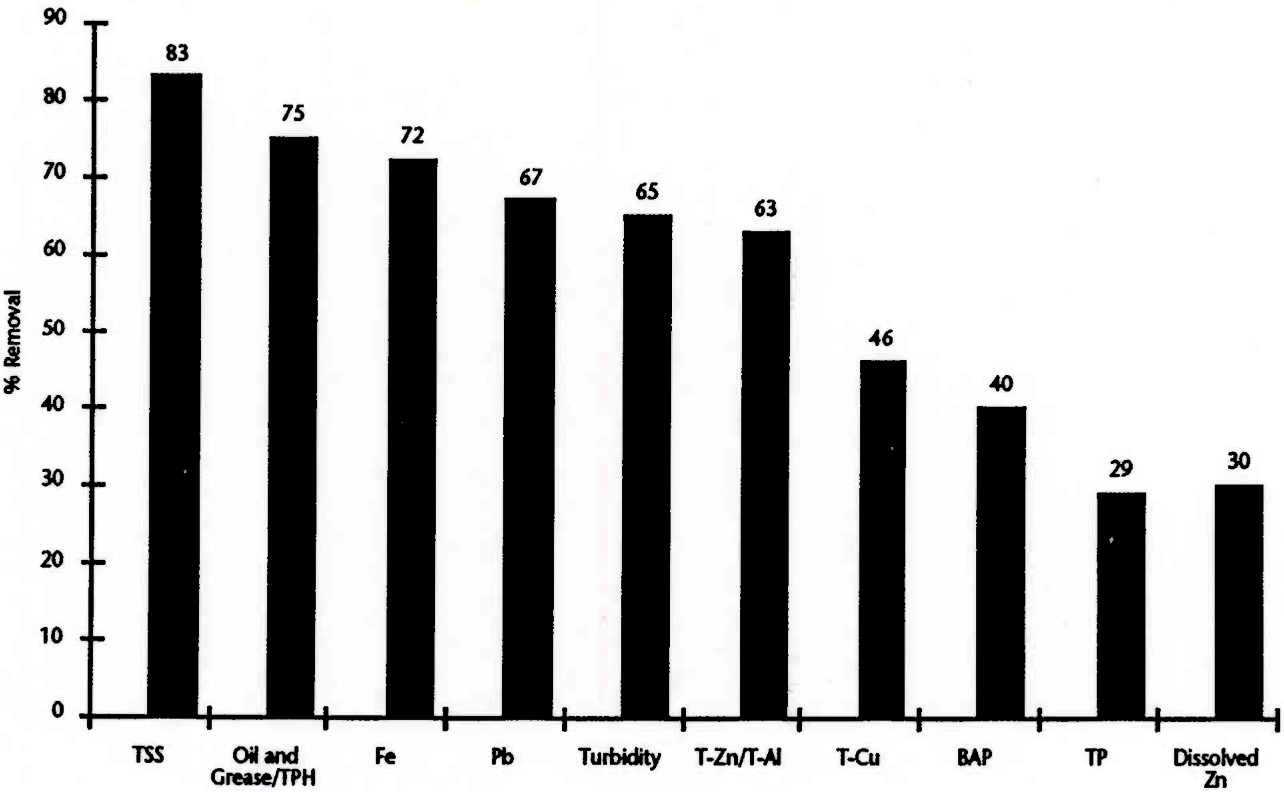

Figure 1-1. Pollutant Removal of a 200-Foot Swale (9-minute Average Hydraulic Residence Time)

Hydraulic Residence Time

A hydraulic residence time of about 9 minutes (at the 200-foot length configuration) resulted in good removal of particulate pollutants, oil and grease, and TPH. This residence time is recommended as a basis for design for most biofiltration swale applications. Longer residence times are recommended if solids removal in excess of about 80 percent is desired.

When the hydraulic residence time was reduced to an average of 4.6 minutes (at the 100-foot length configuration) visual observations and performance data for zinc and iron indicated that pollutant removal performance was poorer than for the 9-minute, 200-foot configuration. Because of a high variance in average removal for the 100-foot configuration, data for parameters other than zinc and iron could not be shown to be significantly different from those observed for the longer detention time configuration. However, it is suggested that a residence time of 4 to 5 minutes is not adequate to assure consistently good pollutant removals, particularly for storms with significant rainfall peaks. More work is needed before a residence time of less than 9 minutes can be recommended with confidence as adequate for biofiltration swale design.

Manning's n Value

This study has shown that Manning's n did not vary significantly with changes in slope between 3 and 4 percent, but did vary with flow rate. Variation was also seen with grass height (6 inches vs. 12 inches). For a grass height of 6 inches and a flow rate of 0.51 feet per second, the Manning's n values observed were between 0.192 to 0.198 (dimensionless). Considering uncertainties involved in this study, and erring on the conservative side, a Manning's n of 0.20 is recommended for swale design for stormwater treatment applications.

In applying this information, the user should be aware that the Manning's n of 0.20 was measured for grass having blade densities averaging from 600 to 1,600 blades/ft^2. The swale had infrequent maintenance (mowing and other lawn maintenance activities such as aeration and fertilization). For regularly mowed and maintained swales, grass is likely to be denser, and hence the Manning's n value may be higher than the 0.20. Therefore, it is recommended that the Manning's n value of 0.20 found in this study be adopted as the *minimum* value for biofiltration swale design. More work should be done to investigate Manning's n for regularly mowed grass.

Before mowing, when grass was about 12 inches, the Manning's n determined for the same swale was 0.24. It is reasonable to apply this higher Manning's n value in situations where swales can only be infrequently maintained, such as for rural roads. However, in general, regular mowing of swales is recommended.

RECOMMENDATIONS FOR PLANNING, DESIGN, INSTALLATION, AND MAINTENANCE

Based on the collective experience of the Biofiltration Project team, recommendations were made in the areas of landscaping, design parameters, installation, maintenance, and enforcement. These recommendations supplement the primary data on pollutant removal effectiveness and Manning's n values collected during the project. Highlights are summarized:

- Landscaping can be integrated into water quality swales, but precautions are needed to prevent shading and leaf drop, which can kill the grass, and transport of soil from the planting beds into the swale.

- Uniform spreading of flow at the head of the swale is important for effective pollutant removal.

- Maximum design velocity should not exceed 0.9 feet per second to prevent exceedance of the treatment capability of the swale.

- A hydraulic residence time of 9 minutes is recommended for pollutant removals of about 80 percent of total suspended solids. If higher levels of performance are desired, longer residence times are recommended.

- Swale width should be limited to about 7 to 8 feet (the width of a typical backhoe loader) unless special measures are provided to assure an even level of the swale bottom, uniform flow spreading, and management of flows to prevent formation of low-flow channels.

- No specific swale length is recommended, but the recommended hydraulic residence time and width will result in a minimum length for a particular set of geometric and vegetation characteristics. In the case of the 200-foot swale studied, application of these residence time and width criteria would result in a minimum length of 125 feet.

- Swale slopes should be between 2 and 4 percent. Underdrains should be installed if slopes are less than 2 percent. If standing water is likely for prolonged periods (for example, several weeks) due to low gradients or interception of the water table or base flow, wetland vegetation should be used rather than grass.

- Water depth should be limited to no greater than one half the height of the grass up to a maximum of 3 inches of water depth. For taller grass, water depth should be less than or equal to one third the grass height.

- Regular mowing is strongly recommended. Not only does regular mowing encourage thicker, healthier grass, but leaves, litter, and other obstructions to good flow spreading are removed in the process of mowing.

- Regular maintenance of swales is key to assuring good water quality performance. Specifying mowing frequencies, regular inspection and repair on site plans is recommended. Establishing performance bonds retained through the first year of operation has also been effective in assuring early problems are addressed.

SECTION 2

INTRODUCTION

In the last two decades, uncontrolled storm runoff that accompanies development has posed a substantial and pervasive threat to the quality of the nation's lakes, rivers, and streams (Meybeck & Helmer, 1987; National Research Council, 1987, Rogers & Rosenthal, 1988). Initially stormwater managers tried simply to control the volume or quantity of storm runoff. However, significant impacts were still occurring in many water bodies. Recently, degradation of water quality caused by nonpoint source pollution, including urban stormwater runoff, has been acknowledged as a major unfinished agenda in meeting the country's clean water goals (USEPA, 1989, General Accounting Office, 1987, 1989, Davis & Simon, 1989, Thompson, 1989).

In order to reduce the impacts of the relatively dilute pollutant loads carried by urban runoff cost-effectively, stormwater managers have advocated the use of passive, technically simple, and relatively flexible methods for treating urban runoff, termed best management practices (BMPs) (Roesner et al., 1989, De Groot, 1982). Wet detention ponds, infiltration basins, constructed wetlands, as well as biofiltration devices such as filter strips and grassy swales are some of the BMPs that have been suggested or required for stormwater quality management, both locally and nationally (*King County Surface Water Design Manual*, 1990, *Washington State Department of Ecology Draft Stormwater Manual*, 1991, *Water Quality Best Management Practices Manual*, 1989, *Water Quality Design Manual*, 1991, Schueler, 1988).

Unfortunately, good data on the pollution removal performance of these systems is still relatively scarce. One major exception is the study of wet detention ponds done through the Nationwide Urban Runoff Program (NURP) (Athayde et al., 1983). The NURP report also provided design criteria for wet ponds to meet specific water quality objectives. Similar performance data for other stormwater treatment alternatives is far less comprehensive, though equally important.

This report provides information on the pollutant removal effectiveness of a grassy swale located in Mountlake Terrace, Washington, in treating runoff from a small suburban drainage basin. The Project team believes information of this kind is critically important. By providing better information about the kind of water quality treatment biofiltration swales can and cannot provide, better decisions can be made about how to protect water bodies, and scarce dollar resources can be allocated most effectively. It does little good to require that land development projects provide biofiltration for stormwater treatment if in reality the biofiltration is not effectively removing the pollutants of concern. In this case, other control methods need to be identified. On the other hand, if biofilters work well, they could be used more frequently and in more varied situations to control pollution from urban runoff.

In addition to studying the treatment efficiency of a particular swale, this report investigates the value of the Manning's roughness coefficient for grassy swales used for stormwater treatment applications. It also collects the experience of the Project team to provide general recommendations for the application and management of biofiltration swales.

In order to meet the challenging task of protecting lakes, streams, and marine waters in the face of rapid population growth, resource managers need accurate, relevant, and reliable information. We must know what the identified management tools can be expected to do, as well as how to keep those tools operating at peak efficiency, and how to fix them should they need repair. Given this information, we will be able to spend society's limited resource protection money more wisely.

It is our hope then, that this report will provide some of the information necessary to increase the effectiveness and efficiency with which stormwater managers are able to protect aquatic resources through the appropriate use of grassy swales and other biofiltration mechanisms.

SECTION 3

PROJECT GOALS AND OBJECTIVES

Biofiltration is a general term referring to the physical ability of vegetation to remove pollutants from water. Grassy swales, as their name implies, are shallow, typically broad-bottomed ditches in which a dense growth of grass is established. The use of vegetated swales is not new, but their application to water pollution control objectives is relatively recent.

Pollutant removal in a biofiltration swale depends most fundamentally on the time that water remains in the swale (the residence time) and the extent of its contact with vegetation and soil surface. Good vegetation and soil contact is required to promote the operation of the various mechanisms that capture and transform pollutants. Spreading flow in minimal depth over a wide swale is best from this standpoint. Water residence time depends on the volume of runoff, the velocity at which it travels, and the length over which it flows. Velocity, in turn, is a function of the cross-sectional area of the flow (the width and depth), the channel slope, and the friction imparted by the vegetation. Therefore, biofilter performance depends on a number of geometric, hydrologic, and hydraulic variables, namely the following:

- Swale width and length
- Flow depth
- Volumetric flow rate
- Slope
- Vegetation characteristics

Any or all of these variables can theoretically be manipulated to maximize water residence time and contact and achieve a desired level of performance, provided adequate data are available to relate performance to swale characteristics.

With thorough understanding of these relationships, a designer could increase residence time by, for instance, increasing depth or width, diverting some flow to another biofilter or other treatment system to reduce flow rate, decreasing slope, providing for a denser grass stand, or any other combination of these options. There are, on the other hand, reasons for restricting flexibility in some of these areas. For example, Horner (1988) observed standing water, sometimes resulting in poor grass growth, in flatly sloped swales, especially those sloping longitudinally less than 1 percent. Similarly, obtaining a very dense stand of grass could imply heavy fertilization, which would conflict with nutrient removal objectives.

A general objective of this project was to assemble as much information as possible to aid in choosing ranges of the crucial variables that would produce effectively operating biofiltration swales. To this end, the report presents recommendations derived from the experience of team members about the effective application and management of swales. Good design must be accompanied by effective implementation—good planning and proper installation, operation, and maintenance—for the full water quality benefits of swales to be realized.

The project also had three specific objectives:

1. To determine the types and amounts of pollutants that are removed from stormwater, during typical storm events, by a grassy swale designed according to Phase I design criteria (Horner, 1988)
2. To determine whether equivalent pollutant removal performance could be achieved in a grassy swale with length less than 200 feet if a proportionate increase in width was provided
3. To measure Manning's n, the coefficient of roughness in the Manning's Equation, in a functioning grassy swale

Although a number of other questions were of interest to the Project team, these three objectives were identified as the most valuable for investigation, considering cost, sampling difficulty and the overall state of knowledge about the performance of grassy swales.

Although the Project team attempted to explore objective 2, whether equivalent pollutant removal performance could be achieved with a wider but shorter swale, problems were encountered in finding a satisfactory field application that could address the question directly. In the end, this objective was modified to explore the question of performance under two different residence times. One residence times was associated with a 200-foot swale and the other with a 100-foot swale with a modified flow regime. Specifics are discussed further in Section 5.

In investigating the question of performance for two different residence times, the study was at the same time able to gather information on the effectiveness of a typical 200-foot configuration (objective 1), because it was needed for comparison to the modified swale. This basic information on swale performance was also important in its own right. Few sources of data on the effectiveness of grassy swales under Pacific Northwest rainfall and runoff conditions are available, other than studies done by Wang et al. (1981). Additional data were sought through this study to increase certainty that the pollutant removal performance seen in the University of Washington study would be provided in other urban/suburban grassy swale applications, and to judge the treatment performance for additional parameters of concern.

For instance, one area of interest was the performance of swales in removing nutrients from stormwater. Excess nutrients have the potential to contribute to serious water quality degradation. Phosphorus enrichment can lead to excess algae growth in lakes and other water bodies, especially those with poor circulation and long residence times. Several Puget Sound area lakes are phosphorus sensitive, including Lake Ballinger, Green Lake, and Lake Sammamish. Knowing the removal efficiency of phosphorus from monitoring data is, then, important in order for stormwater managers to use biofilters efficiently in achieving water quality objectives for specific water bodies.

The Project team wanted to establish a value for Manning's n based on field measurement since a wide variety of values are currently in use for swale design (*Guidebook, Water Quality Swales*, 1990). Because the value of Manning's n significantly affects the size of swales, information on this coefficient is of interest to both resource managers and land developers.

By having a better understanding of the pollutants that swales can and cannot remove, and by understanding critical aspects of design and implementation, a more realistic assessment of the appropriateness of using grassy swales in specific pollution control situations is possible. The next section provides background information about previous research in the area of biofiltration and provides a basis for further discussions of experimental design.